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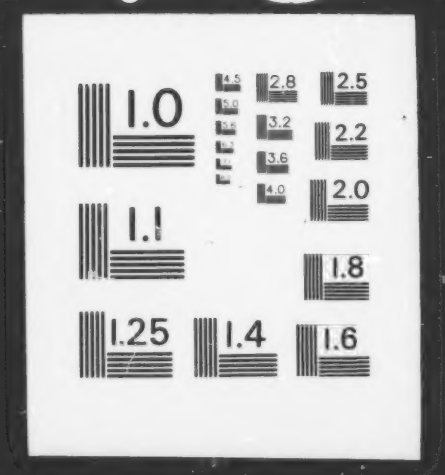

PB90-131525

Diffusion in Near-Shore and Riverine Environments

(U.S.) Environmental Protection Agency, Seattle, WA

Oct 89

U.S. Department of Commerce
National Technical Information Service
NTIS

PB90-131525

DIFFUSION

IN

NEAR-SHORE AND RIVERINE

ENVIRONMENTS

EPA 910/9-87-168
John Yearsley
EPA Region 10
October 1989

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16. Abstract (Limit: 200 words)

Steady-state solutions to the diffusion-advection equation are obtained for waste discharges under the following conditions: (1) a vertically well-mixed ocean with a coastline and and a steady, uniform current parallel to the coastline; (2) a vertically well-mixed river with a steady, uniform current. The method of images is used to obtain solutions for these environments. It is assumed that the discharge contains a constituent whose decay characteristics can be described by a first order reaction. A listing of the FORTRAN 77 source code implementing the solution technique is provided in the report.

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INTRODUCTION

The dispersal of industrial or municipal waste discharges through a diffuser system is generally characterized by the following two phases (Figure 1.)

1) Initial dilution in the vicinity of the discharge. Initial dilution is due to mixing processes generated by buoyancy and momentum associated with the discharge.

2) Far-field dilution associated with larger time and distance scales. Far-field dilution is a result of mixing processes in the receiving waters. Wind stress, tidal forces and gravitational convection are oceanic and estuarine processes providing sources of energy for far-field dilution. In rivers, interaction between the flowing river and its side and bottom boundaries generate turbulence leading to diffusion-like mixing processes.

For the purposes of estimating the dilution associated with discharge from a diffuser, the U.S. Environmental Protection Agency has supported the development of a number of initial dilution models. The theory and software implementing the theory are described by Muellenhoff et al (1985). Methods for estimating the far-field dilution are generally based upon solutions of the diffusion-advection equation

$$\frac{\partial C}{\partial t} + \mathbf{u} \cdot \nabla C = \nabla \cdot \kappa \nabla C + \Phi(\mathbf{x},t) - \Gamma(\mathbf{x},t) \qquad (1)$$

where,

C = the constituent concentration,

$\mathbf{u}$ = the velocity vector,

$\mathbf{x}$ = the position vector,

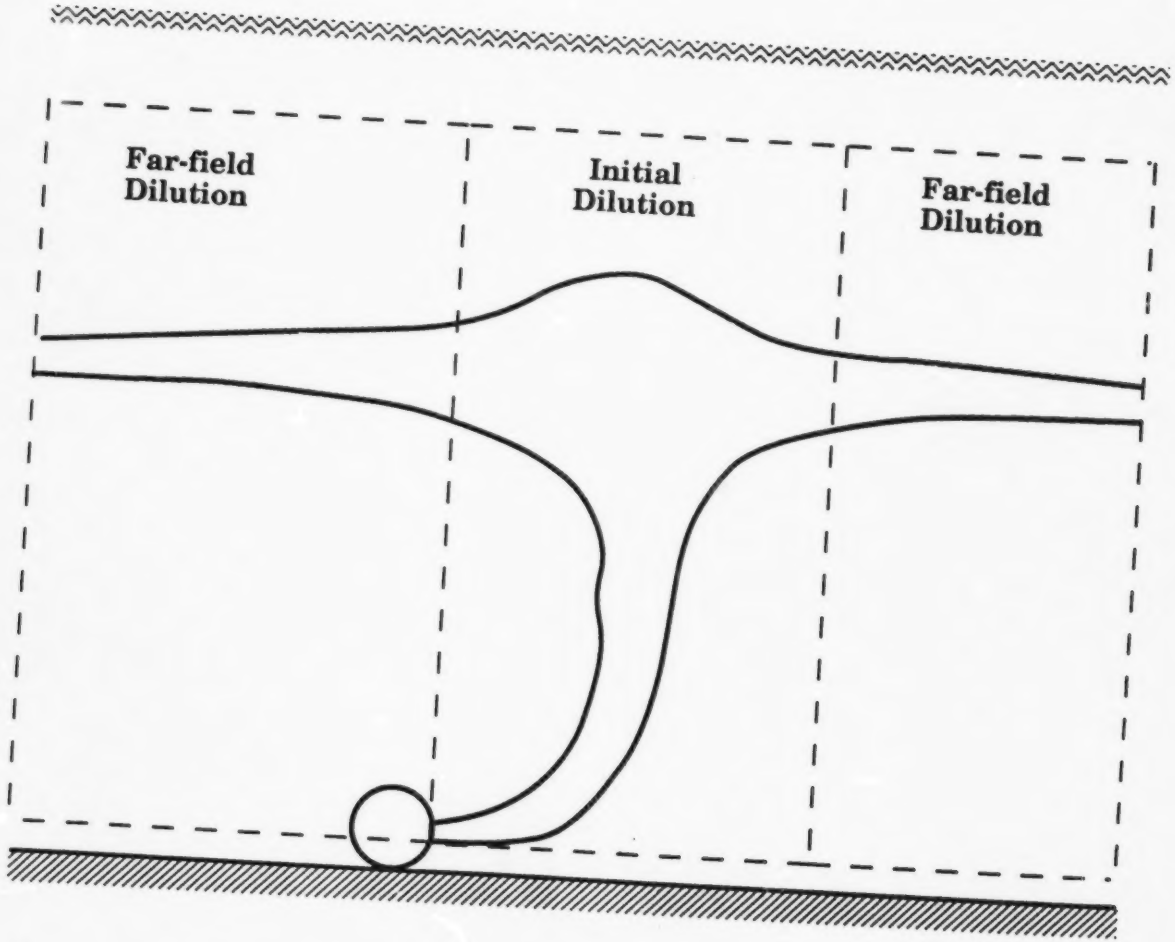

Figure 1. Schematic of discharge field showing the areas in which initial dilution and far-field dilution occur.

t = time,

κ = the coefficient of turbulent diffusion for the constituent,

$\Phi(\mathbf{x},t)$ = the source term,

$\Gamma(\mathbf{x},t)$ = the sink term.

Under the following assumptions:

1) The vertical extent of the waste field remains constant and the constituent, C, is mixed uniformly and instantaneously in the vertical.

2) The current is uniform and steady .

3) Turbulent diffusion processes are important only in the lateral (y) direction.

4) The diffusion coefficient, κ, is a function of plume width and plume width, in turn, is a function of downstream (x) distance, only

5) The decay of constituent, C, is a first-order reaction. This means that the rate of change of the constituent, C, in a static environment is a linear function of the constituent, C.

equation (1) reduces to:

$$u\frac{\partial C}{\partial x} = \kappa\frac{\partial^2 C}{\partial x^2} - kC \qquad (2)$$

By defining a new variable, C', such that

$$C(x,y) = C'(x,y)\, e^{-\frac{kx}{u}} \qquad (3)$$

equation (2) becomes

$$u\frac{\partial C'}{\partial x} = \kappa\frac{\partial^2 C'}{\partial x^2} \qquad (4)$$

For a vertical line source in a water body of infinite horizontal extent discharge at x=0, y=y_0, the solution to equation (4) (Edinger and Polk, 1969) is

$$C'(x,y) = \frac{C_0 e^{-\frac{(y-y_0)^2}{4\kappa t}}}{2\sqrt{\pi \kappa t}} \qquad (5)$$

where t = x/u.

Given a vertical line source at x=0, y=y_0, the complete solution to equation (2) is then

$$C'(x,y) = \frac{C_0 e^{-kt} e^{-\frac{(y-y_0)^2}{4\kappa t}}}{2\sqrt{\pi \kappa t}} \qquad (6)$$

For the case of a water body of infinite lateral extent, and for a diffuser whose center is located at x = 0, y = 0, Brooks (1960) obtained solutions to the problem of describing the dispersal of effluent from a diffuser of length, B, (Figure 2) by applying the Principle of Superposition. This is accomplished by integrating equation (6) along the length of the diffuser

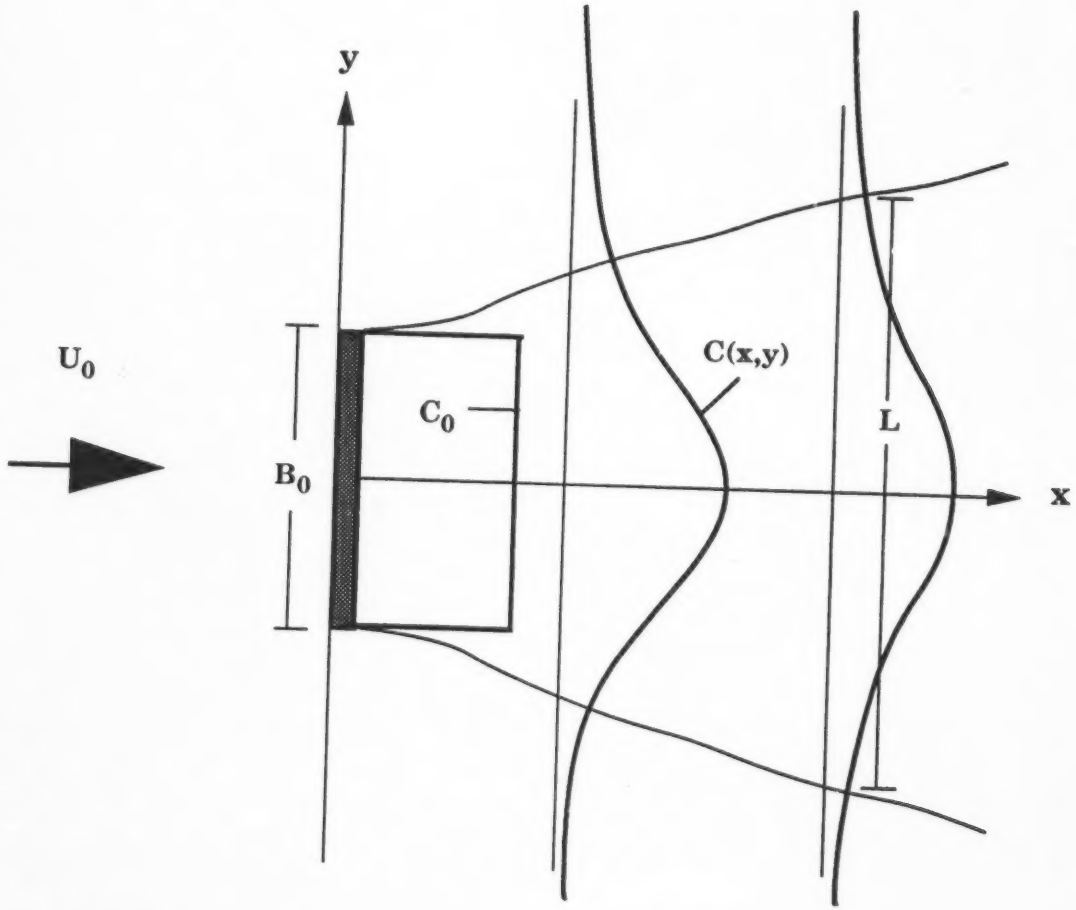

Figure 2. Schematic diagram of waste discharge through a diffuser into an oceanic environment with constant depth and constant speed perpendicular to the axis of the diffuser (after Brooks, 1960).

$$C(x,y) = \frac{C_0 e^{-kt}}{2\sqrt{\pi \kappa t}} \int_{-B/2}^{B/2} e^{-\frac{(y-y')^2}{4\kappa t}} dy' \qquad (7)$$

When the coefficient of lateral eddy diffusivity, κ, can be described as a function of the downstream coordinate, x, such that

$$\kappa(x) = \kappa_0 f(x)$$

equation (7) can be solved by defining a transformed x-coordinate

$$dx' = f(x)\, dx$$

and replacing the variable t in equation (5) by $t' = x'/u$.

Brooks (1960) provides solutions for three different functional forms

I. $\kappa = \kappa_0 \quad ; x' = x$

II. $\frac{\kappa}{\kappa_0} = \frac{L}{B} \quad ; \frac{x'}{B} = \frac{1}{2\beta}\left[(1 + \beta\frac{x}{B})^2 - 1\right]$

III. $\frac{\kappa}{\kappa_0} = \left(\frac{L}{B}\right)^{4/3} ; \frac{x'}{B} = \frac{1}{2\beta}\left[(1 + \frac{2}{3}\beta\frac{x}{B})^3 - 1\right]$

where

L = measure of the plume width

$$\beta = \frac{12\,\kappa_0}{uB}$$

In most cases involving the discharge of municipal or industrial effluents, the body of water receiving the discharge is not of infinite extent . Typically, such discharges are along a coastline or into a river. In such cases the effects of the boundaries may be important, and the solution methods used by Brooks must be modified to account for the effects of the boundaries. This report describes methods for obtaining solutions when the boundaries are idealized conditions for discharges along coastlines or into a river.

COASTAL DISCHARGES

This section considers the discharge of effluent through a diffuser of finite length along a coastline with the ocean current parallel to the coastline (Figure 3). This problem can be solved by the Principle of Superposition if it is assumed that there is fictitious discharge in addition to the actual discharge. The fictitious discharge is in every way the same as the actual discharge with the exception that it is located such that it is the reflection of the actual discharge with reference to the coastline (Figure 4). The solution is given by

$$C(x,y) = \frac{C_0 e^{-kt}}{2\sqrt{\pi \kappa_0 t'}} \left[\int_{-B/2-y_0}^{B/2-y_0} e^{-\frac{(y-y')^2}{4 \kappa_0 t'}} dy' + \int_{-B/2+y_0}^{B/2+y_0} e^{-\frac{(y-y')^2}{4 \kappa_0 t'}} dy' \right] \quad (8)$$

Equation (8) can be solved numerically by considering the diffuser to be made up of a large number of very short elements and treating the integrals as finite sums. The transformed x-coordinate used by Brooks (1960) can be incorporated into this solution for purposes of accommodating various functional forms for the coefficient of eddy diffusion coefficient. For open ocean conditions Brooks (1960) recommends the use of the 4/3 law based upon both theoretical and experimental results. The existence of boundaries, however, restricts the size of the eddies characterizing the turbulence and, as a result, some of the assumptions leading to the 4/3 law may be violated. For coastal discharges the choice of an appropriate functional form for the coefficient of eddy diffusivity must, therefore, include consideration of the effects of the boundaries.

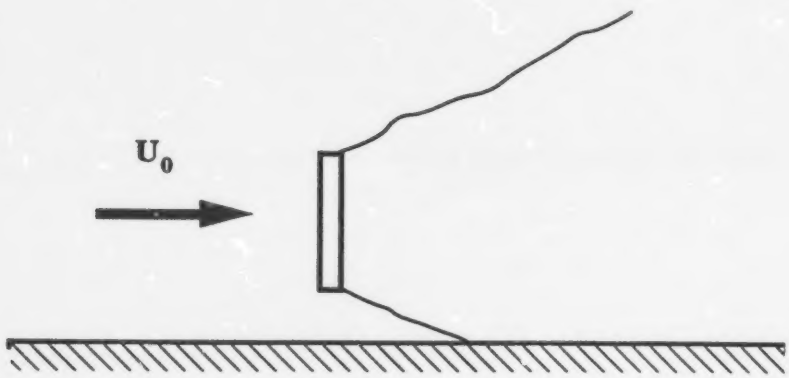

Figure 3. Discharge to an oceanic environment in the vicinity of a coastline.

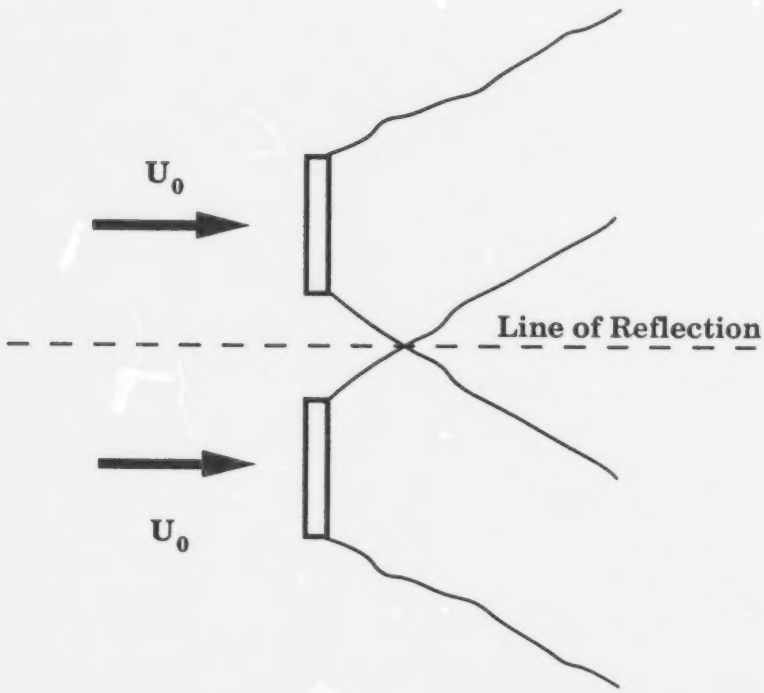

Figure 4. Diffuser source reflected about coastline for purposes of obtaining solution to the diffusion/advection equation.

Software which implements this solution method in FORTRAN 77-compatible code is described in Appendix A. The software provides the option for choosing any of the three functional forms for the coefficient of eddy diffusivity described above. However, the value of the initial diffusion coefficient, κ_0, is estimated within the program using the relationship:

$$\kappa_0 = \alpha B^{4/3}$$

where B = the length of the diffuser, feet,

α = the dissipation factor, $feet^{2/3}$

κ_0 = the initial coefficient of eddy diffusivity, $feet^2/second$.

Based upon the results of numerous experiments in oceanic environments (Fischer et al; 1979), the dissipation factor, α, has a value in the range from 0.0002 to 0.001. The program described in Appendix A assumes a value of 0.001 $feet^{2/3}$.

RIVER DISCHARGES

The case of river discharges (Figure 5) can be solved with the method used by Brooks by considering an infinite number of discharges. The location of these discharges are reflections with respect to the river shoreline as shown in Figure 6. The solution is given by

$$C(x,y) = \frac{C_0 e^{-kt}}{2\sqrt{\pi \kappa_0 t'}}\left[\int_{-B/2-y_0}^{B/2-y_0} e^{-\frac{(y-y')^2}{4\kappa_0 t'}} dy' + \int_{-B/2+y_0}^{B/2+y_0} e^{-\frac{(y-y')^2}{4\kappa_0 t'}} dy' + \int_{-B/2-2W-y_0}^{B/2-2W-y_0} e^{-\frac{(y-y')^2}{4\kappa_0 t'}} dy' + \int_{-B/2+2W+y_0}^{B/2+2W+y_0} e^{-\frac{(y-y')^2}{4\kappa_0 t'}} dy' + \; . \; . \; . \right] \quad (9)$$

Equation (9) can be solved numerically by assuming the diffuser is comprised of a large number of short elements and by considering a finite number of reflected images. Software implementing this solution method is described in Appendix B.

For the case of the river discharges, the coefficient of eddy diffusivity is assumed to be constant for a given set of hydrologic conditions. The coefficient of eddy diffusivity is estimated within the software from the following equation (Fischer et al, 1979):

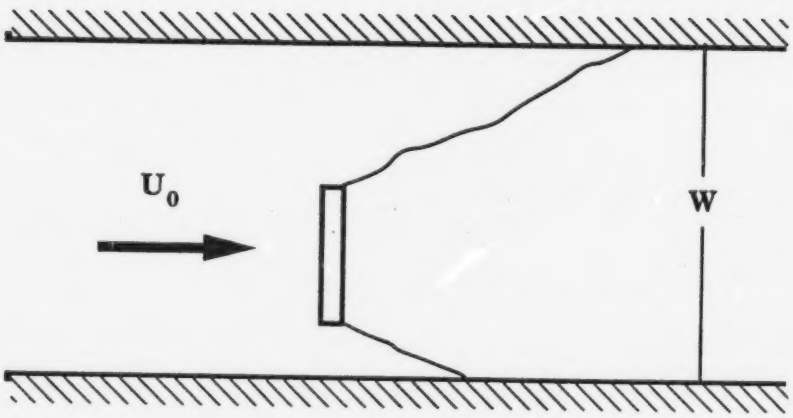

Figure 5. Discharge to a riverine environment.

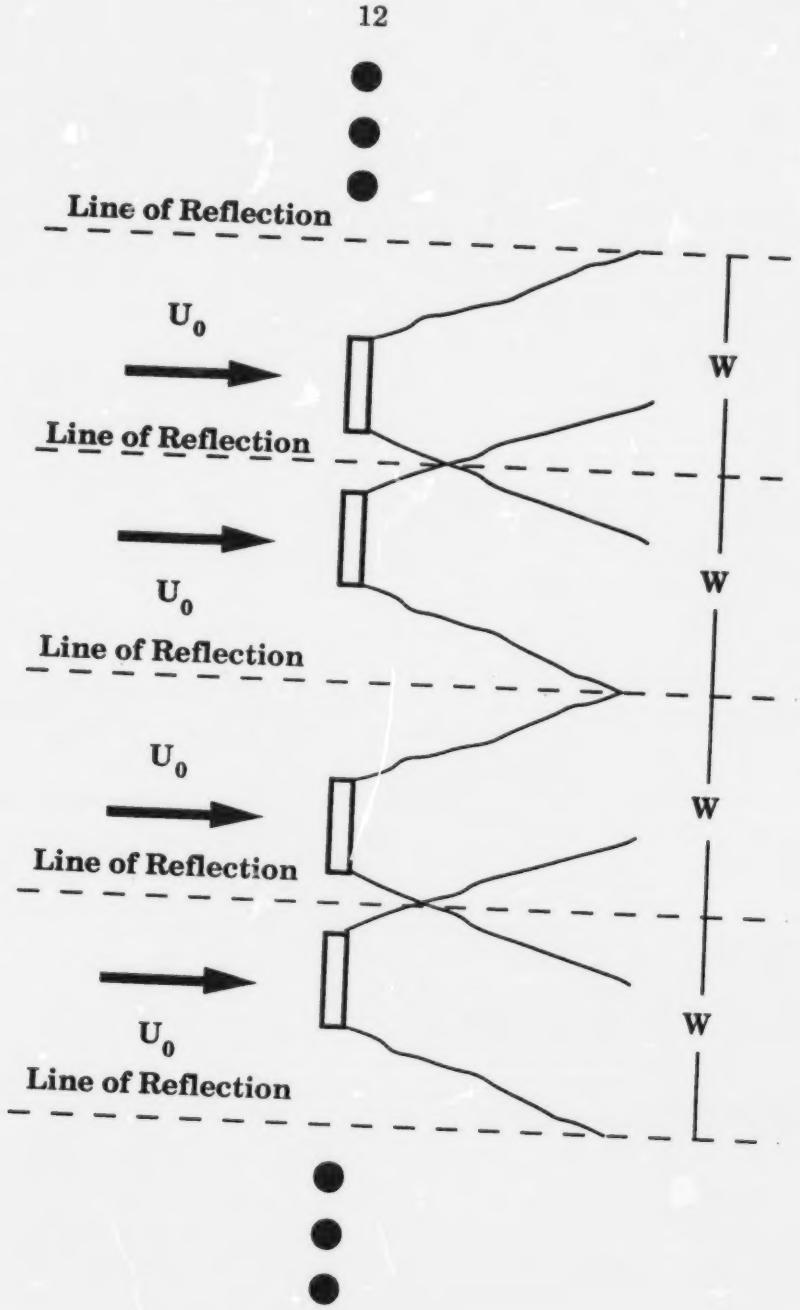

Figure 6. Diffuser source reflected about the river boundary for purposes of obtaining solution to the diffusion/advection equation. ● signifies that reflections continue to $y=+\infty$ and $y=-\infty$.

$\kappa = \kappa_0 = 0.6*Du*$

where

D = the river depth, feet,

$u* = \sqrt{gSD}$ = the shear velocity, feet/second.

S = the slope of the channel, feet/feet.

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Brooks, N.H. 1960. Diffusion of sewage effluent in an ocean current. Proceedings of the International Conference on Waste Disposal in the Marine Environment, Pergamon Press, pp. 246-267.

Edinger, J.E. and E.M. Polk, Jr. 1969. Initial mixing of thermal discharges into a uniform current. Report #1, Dept of Environmental & Water Resources Engineering, Vanderbilt University. 45 pp.

Fischer, H.B., E.J. List, R.C.Y. Koh, J. Imberger and N.H. Brooks. 1979. Mixing in inland and coastal waters. Academic Press.483 pp.

Muellenhoff, W.P., A.M. Soldate, Jr., D.J. Baumgartner, M.D. Schuldt, L.R. Davis, and W.E. Frick. 1985. Initial mixing characteristics of municipal ocean discharges. EPA/600/3-85/073, Environmental Research Laboratory, Narragansett, ORD, Environmental Protection Agency.

APPENDIX A

USER'S GUIDE TO CDIFF

A MODEL FOR ESTIMATING DIFFUSION IN A NEAR-SHORE ENVIRONMENT

The FORTRAN source code listed in Table A.1 implements the numerical solution to the diffusion/advection equation for discharges to an open ocean whose coastline is parallel to the current. The code is written to be compiled with the Microsoft FORTRAN compiler running under MS-DOS 2.0 or greater. The following example demonstrates the use of the program:

Example Problem

Coefficient of eddy diffusivity is a linear function of the downstream distance

First-order decay constant = 0.5 $days^{-1}$

Diffuser width = 100 feet

Current speed = 0.1 feet/second

Initial concentration = 1000

Initial dilution = 20

Distance from center of diffuser to shoreline = 500 feet

Output at 100-foot intervals up to 2000 feet

The interactive session for the example problem is shown in Table A.2.

Table A.1 FORTRAN source code for estimating the diffusion in a coastal environment

```
C
C     THIS PROGRAM ESTIMATES THE RATE OF DISPERSAL OF SOME
C     CONSTITUENT DISCHARGED THROUGH A DIFFUSER INTO A COASTAL
C     ENVIRONMENT NEAR THE SHORELINE.  IMPORTANT PROCESSES ARE
C     LONGITUDINAL ADVECTION, LATERAL DIFFUSION AND FIRST-ORDER
C     DECAY OF THE CONSTITUENT.  THE METHOD OF IMAGES IS USED TO
C     OBTAIN SOLUTIONS AS A FUNCTION OF THE LONGITUDINAL DISTANCE
C     ALONG THE DIFFUSER CENTERLINE AND THE SHORELINE.  THREE
C     DIFFERENT FUNCTIONAL FORMS ARE AVAILABLE FOR SPECIFYING
C     THE COEFFICIENT OF LATERAL EDDY DIFFUSIVITY. FOR MORE
C     INFORMATION SEE:
C
C          DIFFUSION IN NEAR-SHORE AND RIVERINE ENVIRONMENTS
C          EPA 910/9-87-168
C          EPA REGION 10
C
      REAL*4 KRATE
      DIMENSION DIL(50),TITLE(43),CONC(2),YP(2)
      CHARACTER*1 TITLE
      CHARACTER*20 OFILE
      DATA PI/3.14159/,OFILE/' '/,YP/0.0,0.0/,IOUT/2/
C
C     FUNCTION USED TO ESTABLISH INITIAL VALUE OF THE COEFFICIENT
C     OF LATERAL EDDY DIFFUSIVITY.  CORRESPONDS TO DISSIPATION
FACTOR
C     ALPHA=0.001 FEET**4/3
C
      EPS(X)=0.01*((X*12.*2.54)**1.33)/(12.*2.54)**2
C
C     BEGIN
C
   10 CONTINUE
C
C     INPUT PROBLEM SPECIFICATIONS AND COMPUTE IMPORTANT
CONSTANTS
C
      WRITE(*,4000)
 4000 FORMAT(' INPUT PROBLEM DESCRIPTION')
      READ(*,1100) TITLE
      WRITE(*,4020)
 4020 FORMAT(' SPECIFY FUNCTION FOR DIFFUSION'/
     .       ' 1=CONSTANT,2=F(X),3=F(X**4/3)')
      READ(*,*) ITYPE
      OPEN(IOUT,FILE=OFILE,STATUS='NEW')
      WRITE(IOUT,2100) TITLE
```

Table A.1 (cont.) FORTRAN source code for estimating the diffusion in a coastal environment

```
      WRITE(*,4100)
 4100 FORMAT(' DECAY RATE (1/DAYS-BASE E)')
      READ(*,*) KRATE
      XR=KRATE
      KRATE=KRATE/84600.
      WRITE(*,4200)
 4200 FORMAT(' DIFFUSER WIDTH(FT),CURRENT(FT/SEC)')
      READ(*,*) B0,U0
      EPS0=EPS(B0)
      CNST=1./(2.*SQRT(PI*EPS0))
      WRITE(*,4300)
 4300 FORMAT(' EFFLUENT CONCENTRATION, INITIAL DILUTION')
      READ(*,*) C0,S0
      C1=C0
      C0=C0/S0
      WRITE(*,4400)
 4400 FORMAT(' X-INCREMENT, DISTANCE TO SHORELINE')
      READ(*,*) DX,Y0
      YP(2)=Y0
      WRITE(*,4500)
 4500 FORMAT(' NUMBER OF X-INCREMENTS')
      READ(*,*) NX
      DYY=B0/100.
      BETA=12.*EPS0/(U0*B0)
C
C     WRITE HEADER FOR OUTPUT FILE ON UNIT=2
C
      WRITE(IOUT,2150) XR,B0,U0,Y0,C1,S0
C
C     BEGIN CALCULATION LOOP, INDEXING (I) ON THE LONGITUDINAL
C     DISTANCE, X
C
      DO 199 I=1,NX
      X=DX*I
      T0=X/U0
C
C     COMPUTE TRANSFORMED COORDINATE BASED UPON FUNCTIONAL FORM
C     FOR COEFFICIENT OF LATERAL EDDY DIFFUSIVITY
C
      TPRIME=XPRIME(BETA,X,B0,ITYPE)/U0
```

Table A.1 (cont.) FORTRAN source code for estimating the diffusion in a coastal environment

```
C
C     INDEX (ICC) ON THE TWO Y-COORDINATES FOR OUTPUT.
C     YP(2)=DIFFUSER CENTERLINE;  YP(1)=SHORELINE
C
      DO 129 ICC=1,2
      RATIO=0.0
C
C     INDEX (J) ON THE TWO MIRROR IMAGES OF THE DIFFUSER
C
      DO 99 J=1,2
      SSIGN=(-1.)**J
      IF(TPRIME.LT.1.0E-10) GO TO 80
      CONST=CNST/SQRT(TPRIME)   80 CONTINUE
      SSHORE=1.0E10
C
C     INDEX (K) ON THE 100 DIFFUSER INCREMENTS WHICH APPROXIMATE
C     POINT SOURCES.
C
      DO 99 K=1,100
      YK=K
      YDFF=(YK-50.)*DYY
      YIMG=YSIGN*(Y0+YDFF)
      Y=YP(ICC)-YIMG
      A=-(Y**2)/(4.*EPS0*TPRIME)
      RATIO=RATIO+CONST*EXP(A)*DYY
   99 CONTINUE
C
C     ESTIMATE CONCENTRATION ON DIFFUSER CENTERLINE (ICC=2) AND
C     AT SHORELINE (ICC=1)
C
      CONC(ICC)=RATIO*C0*EXP(-KRATE*T0)
  129 CONTINUE
      SMAX=C1/CONC(2)
      IF(CONC(1).LE.1.0E-10) GO TO 150
      SSHORE=C1/CONC(1)
  150 CONTINUE
     WRITE(*,2200) X,CONC(2),CONC(1)
C
C     OUTPUT RESULTS TO UNIT=2
C
      WRITE(IOUT,2200) X,CONC(2),CONC(1),SMAX,SSHORE
  199 CONTINUE
```

Table A.1 (cont.) FORTRAN source code for estimating the diffusion in a coastal environment

```
C
C     CHECK TO SEE IF THERE IS ANOTHER PROBLEM,
C     IF THERE IS RETURN TO STATEMENT 10, IF NOT EXIT
C
      WRITE(*,4600)
 4600 FORMAT(' NEW PROBLEM (ENTER 1), OR QUIT (ENTER ZERO)')
      READ(*,*) I
      IF(I.GT.0) GO TO 10
 1100 FORMAT(80A1)
 2100 FORMAT(1H1///
     .' ****** DIFFUSION/ADVECTION MODEL FOR OCEAN DISCHARGE
******'/
     .' ******
******'/                                EPA REGION 10
     .' ******',1X,43A1,3X,'******'//)
 2150 FORMAT(
     .'
     .'                    DECAY RATE = ',F8.2,' DAYS**-1'/
     .'                DIFFUSER WIDTH = ',F8.0,' FEET'/
     .'                 OCEAN CURRENT = ',F8.1,' FEET/SECOND'/
     .'       DISTANCE TO SHORELINE = ',F8.0,' FEET'/
     .'     EFFLUENT CONCENTRATION = ',F8.0,/
     .'           INITIAL DILUTION = ',F8.1//
     .'     DISTANCE      EST. CONCENTRATION      EST. DILUTION'/
     .'       (FEET)          C/L       S/L          C/L
S/L'//)
 2200 FORMAT(6X,F6.0,4X,F8.2,2X,F8.2,6X,F7.1,2X,F7.1)
      STOP
      END
      FUNCTION XPRIME(BETA,X,B0,ITYPE)
C
C     THIS FUNCTION COMPUTES THE VALUE OF THE TRANSFORMED X-
COORDINATE
C     FOR THREE DIFFERENT FUNCTIONAL FORMS OF THE COEFFICIENT OF
C     LATERAL EDDY DIFFUSIVITY.  BASED UPON THE WORK OF BROOKS
(1960)
C
      GO TO (20,40,60),ITYPE
   20 CONTINUE
      XPRIME=X
      RETURN
   40 CONTINUE
      XPRIME=B0*((1.+BETA*X/B0)**2-1.)/(2.*BETA)
      RETURN
   60 CONTINUE
      XPRIME=B0*((1.+2.*BETA*X/(3.*B0))**3-1.)/(2.*BETA)
      RETURN
      END
```

Table A.2 Interactive session for example problem of discharge toan ocean with a coastal boundary.

```
C:\> CDIFF
SPECIFY FUNCTION FOR DIFFUSION
1=CONSTANT,2=F(X),3=F(X**4/3)
1
PROBLEM DESCRIPTION
TEST PROBLEM
File name missing or blank-Please enter name
UNIT 2? CDIFF.OUT
DECAY RATE (1/DAYS- BASE E)
0.5
DIFFUSER WIDTH (FT), CURRENT (FT/SEC)
100,0.1
EFFLUENT CONCENTRATION, INITIAL DILUTION
1000,20
X-INCREMENT, DISTANCE TO SHORELINE
100,500
NUMBER OF X-INCREMENTS
20
CONTINUE WITH NEW PROBLEM (ENTER 1), OR STOP (ENTER 0)
0
```

where underlined characters are output from the operating system or the model software and characters without underline are input by the user. Furthermore, the above examples assumes that the executable code, CDIFF.EXE, has been transferred from the diskette to the C:-directory on the PC hard drive. The resulting output from this problem (Table A.2) is contained in the ASCII file, CDIFF.OUT, located in the C:-directory on the hard drive.

Table A.3 Output from example problem of discharge along coastline.

```
****** DIFFUSION/ADVECTION MODEL FOR OCEAN DISCHARGE ******
******                    EPA REGION 10                  ******
****** Example Problem                                   ******
                                                        ******

                  DECAY RATE =      .50 DAYS**-1
              DIFFUSER WIDTH =      100. FEET
              OCEAN CURRENT =       .1 FEET/SECOND
  DISTANCE TO SHORELINE =       200. FEET
EFFLUENT CONCENTRATION =      1000.
       INITIAL DILUTION =       20.0

DISTANCE      EST. CONCENTRATION        EST. DILUTION
 (FEET)          C/L       S/L           C/L       S/L

  100.          44.71      .00          22.4    *******
  200.          37.29      .02          26.8   42967.3
  300.          32.28      .21          31.0    4733.1
  400.          28.74      .65          34.8    1530.8
  500.          26.09     1.30          38.3     769.5
  600.          24.01     2.06          41.6     485.0
  700.          22.33     2.87          44.8     348.9
  800.          20.92     3.66          47.8     273.1
  900.          19.73     4.42          50.7     226.3
 1000.          18.70     5.12          53.5     195.3
 1100.          17.80     5.76          56.2     173.7
 1200.          17.01     6.33          58.8     157.9
 1300.          16.30     6.84          61.3     146.1
 1400.          15.67     7.29          63.8     137.1
 1500.          15.10     7.69          66.2     130.0
 1600.          14.58     8.04          68.6     124.4
 1700.          14.12     8.34          70.3     119.9
 1800.          13.69     8.60          73.1     116.2
 1900.          13.30     8.83          75.2     113.2
 2000.          12.94     9.02          77.3     110.8
```

APPENDIX B

USER'S GUIDE TO RDIFF

A MODEL FOR ESTIMATING DIFFUSION IN A RIVERINE ENVIRONMENT

The FORTRAN source code listed in Table B.1 implements the numerical solution to the diffusion/advection equation for discharges to a river. The code is written to be compiled with the Microsoft FORTRAN compiler running under MS-DOS 2.0 or greater. The following example demonstrates the use of the program:

First-order decay constant = 0.5 days-1

River depth = 1 foot

River width = 100 feet

River speed = 1.0 feet/second

Slope of energy grade line = 0.0001 feet/feet

Diffuser width = 10 feet

Distance from center of diffuser to nearest shoreline = 20 feet

Initial concentration = 1000

Initial dilution = 20

Output at 100-foot intervals downstream to 1000 feet

Output at 10-foot interval across the stream

Table B.1 FORTRAN source code for estimating the diffusion in a riverine environment

```
C
C     THIS PROGRAM ESTIMATES THE RATE OF DISPERSAL OF SOME CONSTITUENT
C     DISCHARGED THROUGH A DIFFUSER INTO A RIVER ENVIRONMENT
C     IMPORTANT PROCESSES ARE LONGITUDINAL ADVECTION, LATERAL DIF-
C     FUSION AND FIRST-ORDER DECAY OF THE CONSTITUENT.  THE METHOD OF
C     IMAGES IS USED TO OBTAIN SOLUTIONS DOWNSTREAM FROM THE
C     DISCHARGE.  FOR MORE INFORMATION SEE:
C
C          DIFFUSION IN NEAR-SHORE AND RIVERINE ENVIRONMENTS
C          EPA 910/9-87-168
C          EPA REGION 10
C
      REAL*4 KRATE
      DIMENSION THETA(50,65),XGRID(200),DIL(50),TITLE(43),QFLO(2)
      CHARACTER*1 TITLE
      CHARACTER*20 OFILE
      DATA PI/3.14159/,OFILE/' '/,QFLO/1.0,1.0/,YDIFF/100./
C
C     BEGIN
C
   10 CONTINUE
C
C     INPUT PROBLEM SPECIFICATIONS AND COMPUTE IMPORTANT CONSTANTS
C
      WRITE(*,4000)
 4000 FORMAT(' INPUT PROBLEM DESCRIPTION')
      READ(*,1100) TITLE
      IOUT=4
      OPEN(IOUT,FILE=OFILE,STATUS='NEW')
      WRITE(IOUT,2100) TITLE
      WRITE(*,4100)
 4100 FORMAT(' DECAY RATE (1/DAYS-BASE E)')
      READ(*,*) KRATE
      XR=KRATE
      KRATE=KRATE/84600.
      WRITE(*,4200)
 4200 FORMAT(
     . ' RIVER WIDTH(FT),DEPTH(FT),CURRENT(FT/SEC),SLOPE(FT/FT)')
      READ(*,*) WIDTH,DEPTH,U0,SLOPE
      USTAR =SQRT(32.2*DEPTH*SLOPE)
      EPS0=0.6*USTAR*DEPTH
      CNST=1./(2.*SQRT(PI*EPS0))
      WRITE(*,4300)
 4300 FORMAT(' EFFLUENT CONCENTRATION, INITIAL DILUTION')
      READ(*,*) C0,S0
```

Table B.1 FORTRAN source code for estimating the diffusion in a riverine environment

```
      C1=C0
      C0=C0/S0
      WRITE(*,4400)
 4400 FORMAT(' DIFFUSER: WIDTH(FT), CENTER TO NEAREST SHORELINE(FT)')
      READ(*,*) B0,Y0
      WRITE(*,4450)
 4450 FORMAT(' X-INCREMENT')
      READ(*,*) DX
      WRITE(*,4500)
 4500 FORMAT(' NUMBER OF X-INCREMENTS,Y-INCREMENTS')
      READ(*,*) NX,NY
      Q0=QWST+U0*WIDTH*DEPTH
      CNST=1./(2.*SQRT(PI*EPS0))
      CMIX=C0*QWST/Q0
      CMAX=C0
      YNY=NY
      NDIFF=YDIFF
      DY=WIDTH/YNY
      DIFFY=B0/YDIFF
      NDFF2=1+NDIFF/2
      DO 29 N=1,NX
      XN=N
      XGRID(N)=DX*XN
   29 CONTINUE
      NYP1=NY+1
C
C     WRITE HEADER FOR OUTPUT FILE ON UNIT=4
C
      WRITE(IOUT,2150) XR,DEPTH,WIDTH,U0,B0,Y0,C1,S0
C
C     BEGIN CALCULATION LOOP, INDEXING (NN) ON THE LATERAL DISTANCE, Y
C
      DO 199 NN=1,NYP1
      YN=NN-1
      YP=YN*DY
C
C     INDEX (N) ON THE DOWNSTREAM COORDINATE, X
C
      DO 199 N=1,NX
      XPRIME=DX*N
      TPRIME=XPRIME/U0
      RATIO=0.0
```

Table B.1 FORTRAN source code for estimating the diffusion in a riverine environment

```
C
C
C     INDEX (J) ON THREE IMAGE PAIRS

      DO 99 J=1,3
      YJ=J
C
C
C     INDEX (JJ) ON REFLECTED PAIRS AT EACH J

      DO 99 JJ=1,2
      YSIGN=(-1.)**JJ

C     INDEX (JJJ) ON THE 100 DIFFUSER INCREMENTS WHICH APPROXIMATE
C     POINT SOURCES

      DO 99 JJJ=1,NDIFF
      YDFF=(JJJ-NDFF2)*DIFFY
      YIMG=2.0*(YJ-2.0)*WIDTH+YSIGN*(Y0+YDFF)
      Y=YP-YIMG
      A=-(Y**2)/(4.*EPS0*TPRIME)
      CONST=CNST/SQRT(TPRIME)
      RATIO=RATIO+CONST*EXP(A)*DIFFY
   99 CONTINUE
      IF(RATIO.EQ.0.0) GO TO 120
C
C     ESTIMATE CONCENTRATION AT EACH X,Y PAIR SPECIFIED

      THETA(N,NN)=CMAX*RATIO*EXP(-KRATE*T0)
      IF(THETA(N,NN).GT.CMAX)  THETA(N,NN)=CMAX
  120 CONTINUE
  199 CONTINUE
C
C
C     CHECK TO SEE IF RIVER IS WELL-MIXED

      DO 239 N=1,NX
      CCMAX=0.0
      DO 219 NN=1,NY
      IF(THETA(N,NN).GT.CCMAX) CCMAX=THETA(N,NN)
  219 CONTINUE
```

Table B.1 FORTRAN source code for estimating the diffusion in a riverine environment

```
C
C     IF MAXIMUM CONCENTRATION IS LESS THAN THE WELL-MIXED
C     CONCENTRATION THEN STREAM IS APPROACHING WELL-MIXED CONDITION
C     AND THREE IMAGE PAIRS MAY NOT BE SUFFICIENT.  WHEN THIS OCCURS
C     THE ESTIMATED CONCENTRATION IS REPLACED BY THE UPSTREAM
C     CONCENTRATION WHICH SHOULD LEAD TO APPROXIMATELY WELL-MIXED
C     CONDITIONS.
C
      IF(CCMAX.GT.CMIX) GO TO 230
      DO 229 NN=1,NY
      THETA(N,NN)=THETA(N-1,NN)
  229 CONTINUE
  230 CONTINUE
  239 CONTINUE
C
C     OUTPUT RESULTS TO UNIT=4
C
      WRITE(IOUT,2450) (XGRID(N),N=1,NX)
      DO 249 NN=1,NY
      YN=NN-1
      Y=DY*YN
      WRITE(4,2500) Y,(THETA(N,NN),N=1,NX)
  249 CONTINUE
      CLOSE(4)
C
C     CHECK TO SEE IF THERE IS ANOTHER PROBLEM.
C     IF THERE IS, RETURN TO STATEMENT 10, IF NOT, EXIT
C
      WRITE(*,4600)
 4600 FORMAT(' NEW PROBLEM (ENTER 1), OR QUIT (ENTER ZERO)')
      READ(*,*) I
      IF(I.GT.0) GO TO 10
```

Table B.1 FORTRAN source code for estimating the diffusion in a riverine environment

```
1100 FORMAT(80A1)
2100 FORMAT(1H1///
    .' ******
    .' ******                                                    ******'/
    .' ******                          RDIFF                     ******'/
    .' ****** DIFFUSION/ADVECTION MODEL FOR OCEAN DISCHARGE      ******'/
    .' ******                      EPA REGION 10                 ******'/
    .' ******',1X,43A1,3X,'******'//)
2150 FORMAT(
    .'
    .'                  DECAY RATE = ',F8.2,' DAYS**-1'/
    .'                 RIVER DEPTH = ',F8.2,' FEET'/
    .'                 RIVER WIDTH = ',F8.0,' FEET'/
    .'                 RIVER SPEED = ',F8.1,' FEET/SECOND'/
    .'               DIFFUSER WIDTH = ',F8.1,' FEET'/
    .'     DISTANCE TO SHORELINE = ',F8.0,' FEET'/
    .'     EFFLUENT CONCENTRATION = ',F8.0,/
    .'            INITIAL DILUTION = ',F8.1//)
2450 FORMAT(5X,15F5.0//)
2500 FORMAT(/F5.0,15F5.1)
     STOP
     END
```

Table B.2 Interactive session for example problem of discharge to a river.

```
C:\> RDIFF
INPUT PROBLEM DESCRIPTION
Example Problem
File name missing or blank-Please enter name
UNIT 4? RDIFF.OUT
DECAY RATE (1/DAYS- BASE E)
0.5
RIVER WIDTH (FT), DEPTH (FT),CURRENT (FT/SEC),SLOPE(FT/FT)
100,1,1,0.0001
EFFLUENT CONCENTRATION, INITIAL DILUTION
1000,20
DIFFUSER: WIDTH(FT), CENTER TONEAREST SHORELINE(FT)
10,20
X-INCREMENT
100
NUMBER OF X-INCREMENTS,Y-INCREMENTS
10,10
NEW PROBLEM (ENTER 1), OR EXIT (ENTER 0)
0
```

where underlined characters are output from the operating system or the model software and characters without underline are input by the user. Furthermore, the above examples assumes that the executable code, RDIFF.EXE, has been transferred from the diskette to the C:-directory on the PC hard drive. The resulting output from this problem (Table B.3) is contained in the ASCII file, RDIFF.OUT, located in the C:-directory on the hard drive.

Table B.3 Output from example problem of discharge to a river.

```
******
******                                                    ******
******                        RDIFF                       ******
****** DIFFUSION/ADVECTION MODEL FOR OCEAN DISCHARGE       ******
******                     EPA REGION 10                  ******
****** Example Problem                                     ******
                                                          ******

                  DECAY RATE =       .50 DAYS**-1
                 RIVER DEPTH =      1.00 FEET
                 RIVER WIDTH =      100. FEET
                 RIVER SPEED =       1.0 FEET/SECOND
               DIFFUSER WIDTH =      10.0 FEET
     DISTANCE TO SHORELINE =       20. FEET
    EFFLUENT CONCENTRATION =     1000.
          INITIAL DILUTION =      20.0

      100. 200. 300. 400. 500. 600. 700. 800. 900.1000
  0.   .0   .0   .0   .2   .5  1.0  1.5  2.1  2.7  3.4
 10.  1.4  4.5  6.8  8.5  9.6 10.5 11.1 11.5 11.8 12.0
 20. 47.2 41.2 36.6 33.1 30.4 28.3 26.6 25.1 23.8 22.8
 30.  1.3  4.3  6.6  8.2  9.4 10.3 10.9 11.3 11.6 11.8
 40.   .0   .0   .0   .1   .2   .5   .7  1.0  1.3  1.6
 50.   .0   .0   .0   .0   .0   .0   .0   .0   .0   .1
 60.   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
 70.   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
 80.   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
 90.   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
```